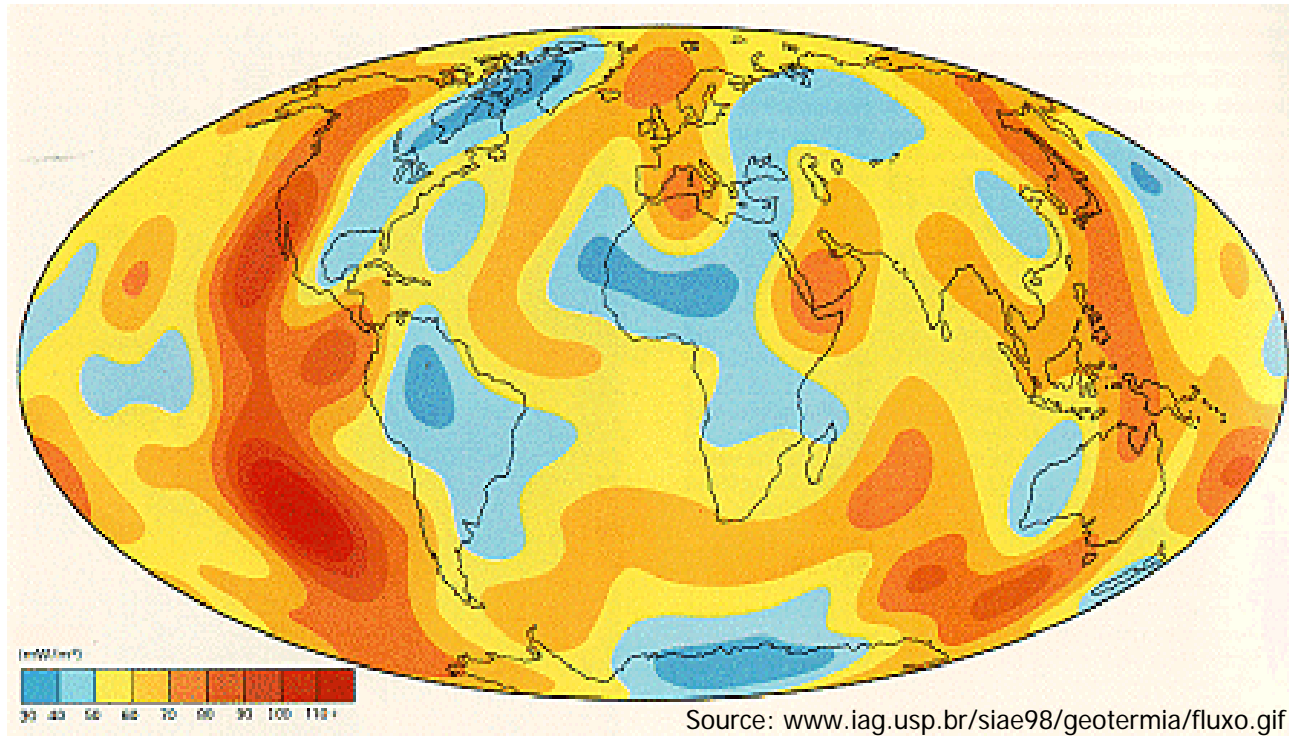


2nd Low-Bin Meeting



Rita Cerdeira, L. M. R. Coelho, J. Garcia

Escola Superior de Tecnologia de Setúbal - Portugal



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- João Garcia
Email: jgarcia@est.ips.pt

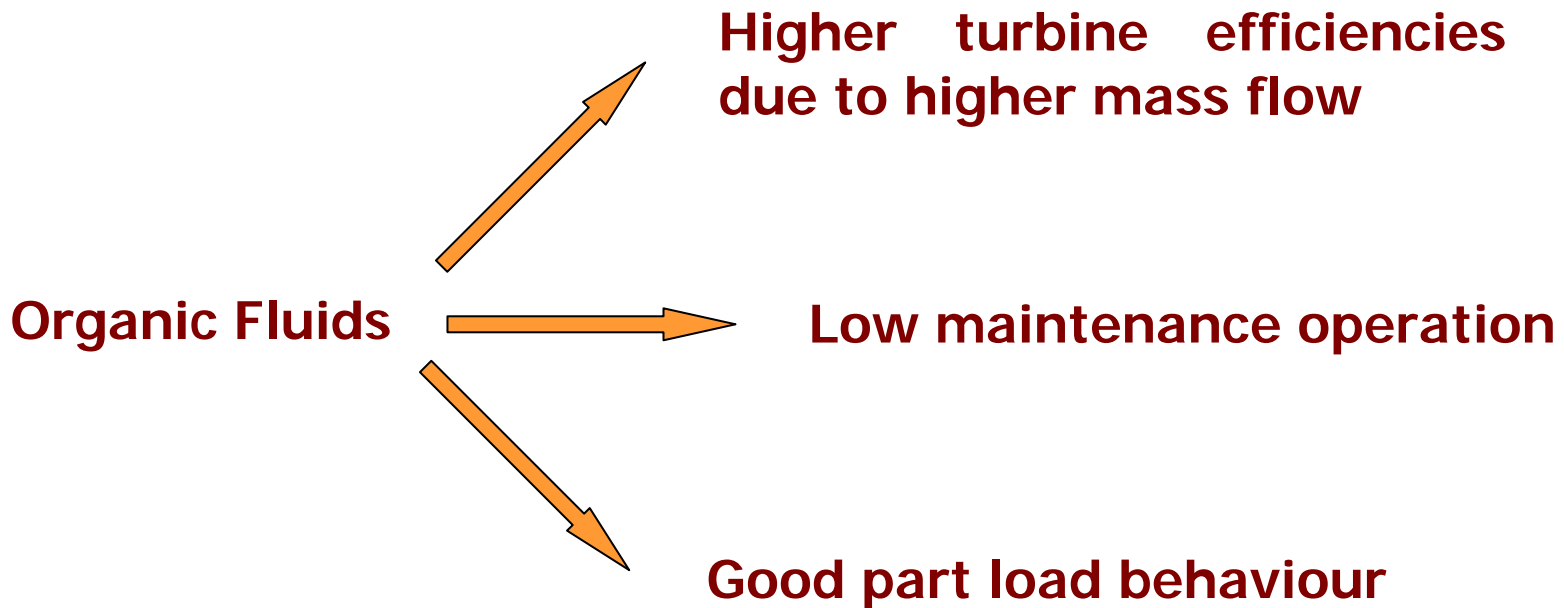


- Rita Cerdeira
Email: rcerdeira@est.ips.pt

MAIN ACTIVITIES OF ESTSETUBAL IN LOWBIN PROJECT:

- **WP#2**
 - Evaluation of working fluids
 - Main working fluids (bibliography) 
 - Computer programs (Cycle-Tempo) 
 - Technology assessment of heat exchangers (assistance)
- **WP#3**
 - Pre-prototype development
 - Laboratory measurements of prototype energy (assistance)
- **WP#5**
 - Monitoring and analysing geothermal energy parameters,
 - Technology validation report
- **WP#6**
 - Presentations in conferences and papers in scientific journals

WORKING FLUIDS





WORKING FLUIDS – Characteristics of the “ideal” working fluid

- High specific heat for enlarging heat capacity
- Fluid's critical point (pressure and temperature) should be above the engine's operating temperature
- High critical temperature for safe elevation of evaporating temperature
- Required operating pressure should not put danger of explosion or rupture
- Fluid's pressure inside the condenser should be above ambient air pressure (prevent air inflow)
- Fluid volume in its gaseous state should be small enough to avoid the need for costly, over-sized turbines, boilers, and condensers.



WORKING FLUIDS - Additional requirements for ORC applications

- Low costs of installation, equipment, maintenance, and operation
- The gas should not require superheating
- Should have a high molecular weight and self-lubricity for the smooth rotation of the turbine and the pump
- At ambient air conditions (pressure and temperature) need to be in a liquid state
- Low latent heat - Capacity to absorb and reject heat easily, lowering heat loss
- High chemical and thermal stability - Maintain its stability at the highest temperatures, non-flammable, non-corrosive and non-toxic
- Lower boiling point and higher vapor pressure than water

MAIN WORKING FLUIDS (BIBLIOGRAPHY)

FLUID		CRITICAL PARAMETERS	
		PRESSURE (bar)	TEMPERATURE (°C)
propane/ethane	0.9 propane/0.1 ethane		90.7
	0.8 propane/0.2 ethane		84.6
	0.7 propane/0.3 ethane		78.4
	0.6 propane/0.4 ethane		72.1
	0.5 propane/0.5 ethane		65.7
propylene		46.1	92.4
R227ae		29.5	101.9
RC318		27.8	115.2
R236fa		32.0	124.92
Isobutane		36.3	134.7
R245fa		36.4	154.05

“Power production from a moderate-temperature geothermal resource”

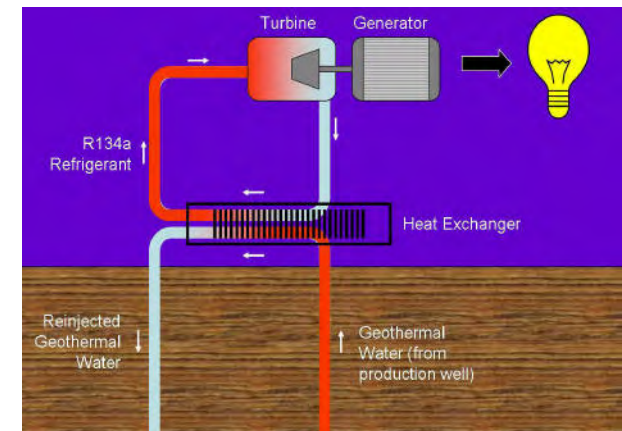
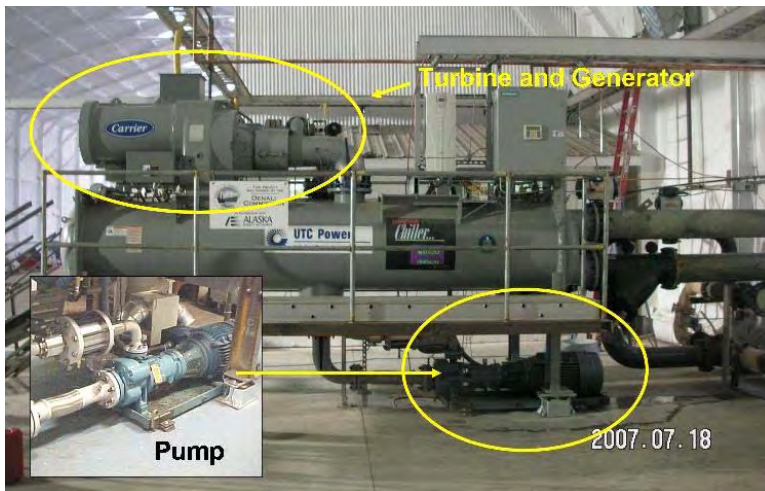
Joost J. Brasz, Bruce P. Biederman, Gwen Holdmann; USA (2005)

Władysław Nowak and Aleksandra Borsukiewicz; Szczecin University of Technology, Poland (2005)

MAIN WORKING FLUIDS (BIBLIOGRAPHY)

FLUID	CRITICAL PARAMETERS	
	PRESSURE (bar)	TEMPERATURE (°C)
R134a	40.7	101.2

- “Research on generation of electricity from the geothermal resources in Simav region, Turkey”; Ramazan Köse; University of Dumlupinar (2004)
Hot Source (Low) Temperature - 74°C
Electric Capacity - 400kWe



Source: <http://www.yourownpower.com/Power/>

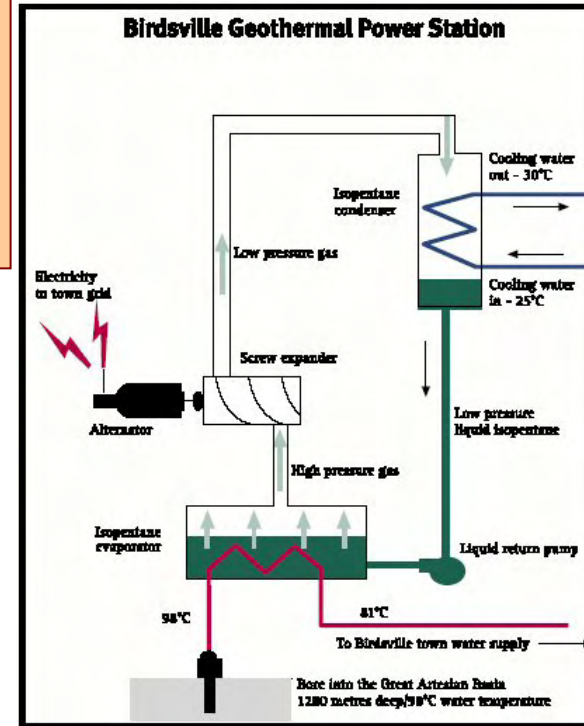
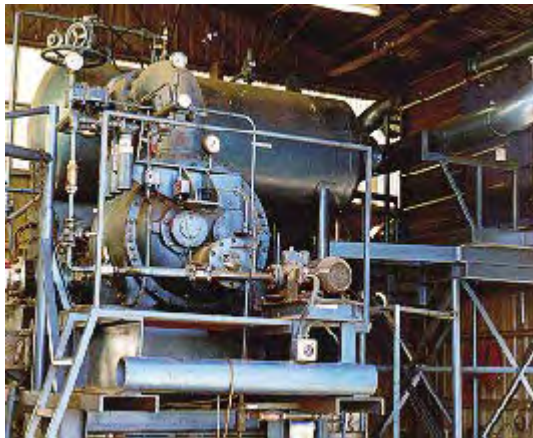
MAIN WORKING FLUIDS (BIBLIOGRAPHY)

FLUID	CRITICAL PARAMETERS	
	PRESSURE (bar)	TEMPERATURE (°C)
isopentane	33.7	187.4

Used in Birdsville geothermal power plant in Queensland, Australia (2005):

Hot Source (Low) Temperature - 98°C

Electric Capacity - 120kWe



Source: http://www.epa.qld.gov.au/publications/p00834aa.pdf/Birdsville_geothermal_power_station.pdf

MAIN WORKING FLUIDS (BIBLIOGRAPHY)

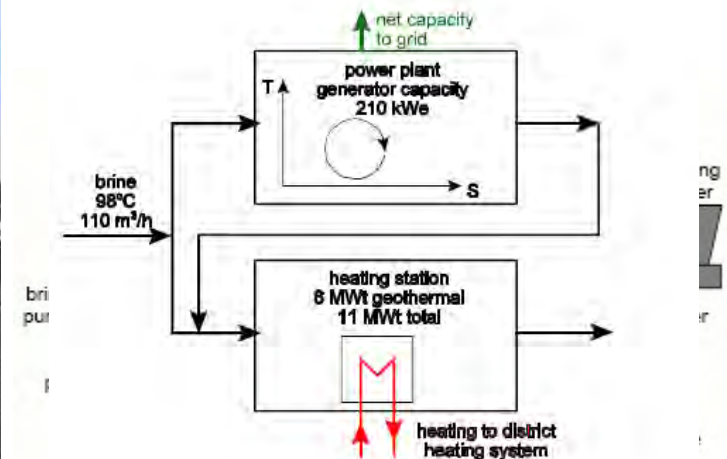
FLUID	CRITICAL PARAMETERS	
	PRESSURE (bar)	TEMPERATURE (°C)
n-perfluoropentane (C ₅ H ₁₂)	20.6	146.8

Used in combined heat and power plant, Neustadt-Glewe, Germany (2003) :

Hot Source (Low) Temperature - 98°C

Heating Capacity - 11 MWth

Electric Capacity - 210kWe



Source: <http://geoheat.oit.edu/bulletin/bull26-2/art8.pdf>

MAIN WORKING FLUIDS (BIBLIOGRAPHY)

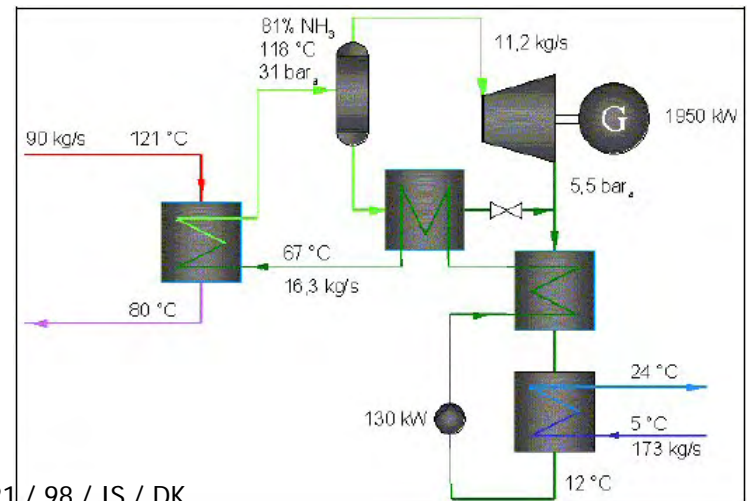
FLUID	CRITICAL PARAMETERS	
	PRESSURE (bar)	TEMPERATURE (°C)
Ammonia (NH ₃) (Kalina)	112.8	132.35

Used in combined heat and power plant, Húsavík , Iceland (2000) :

Hot Source (Low) Temperature - 121°C

Heating Capacity - 40 MWth

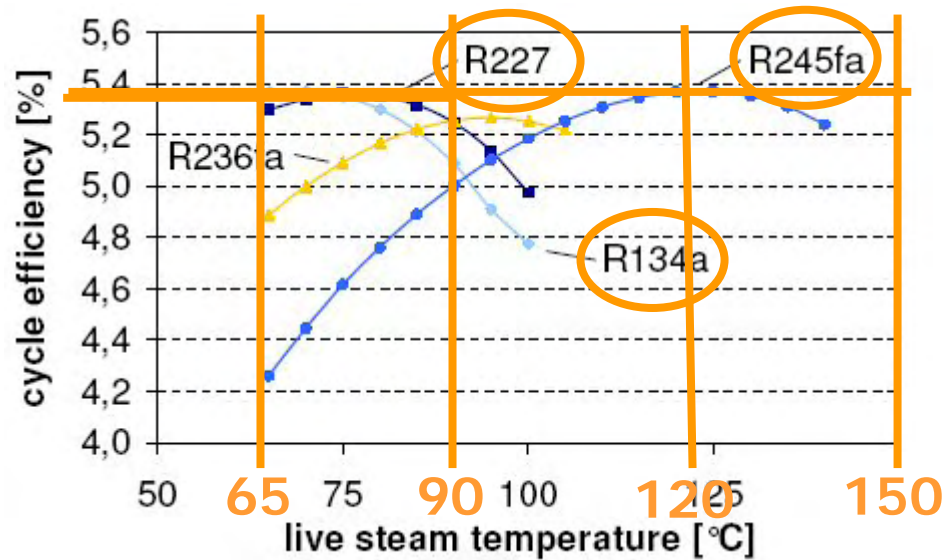
Electric Capacity – 2MWe




Source: Húsavík Energy, Multiple use of geothermal energy, Thermie project nr. GE 321 / 98 / IS / DK

WORKING FLUIDS

According to “The Organic Rankine Cycle – Power Production from Low Temperature Heat”, Hartmut Spliethoff , Andreas Schuster (Technische Universität München – 2006)



- For prototype to generate electricity from low temperature geothermal resource (65-90°C)
- For prototype to cogeneration of heat and power (120-150°C) 



COMPUTER PROGRAMS RESEARCH

- To study different working fluids behaviour in an organic Rankin cycle to:
 - help choosing the best working fluid
- The program should:
 - Allow to model with a great number of different working fluids
 - Allow the user to define different system components and cycle configuration



CYCLE-TEMPO COMPUTER PROGRAM

- Developed by Delft University of Technology (TUDelft) and Institute of Environmental Sciences (TNO), Netherlands
- Tool for thermodynamic analysis and optimization of energy systems by calculating all relevant mass and energy flows in the system
- The number and type of components and sub-systems, and the way in which they are connected are defined by the user
- Fully graphical program
- System configuration can be assembled as a Process Flow Diagram (PFD)
- Capability of performing the exergy analysis of the system (insight into the exergy flows and losses in sub-systems, looking for the optimal system configuration)

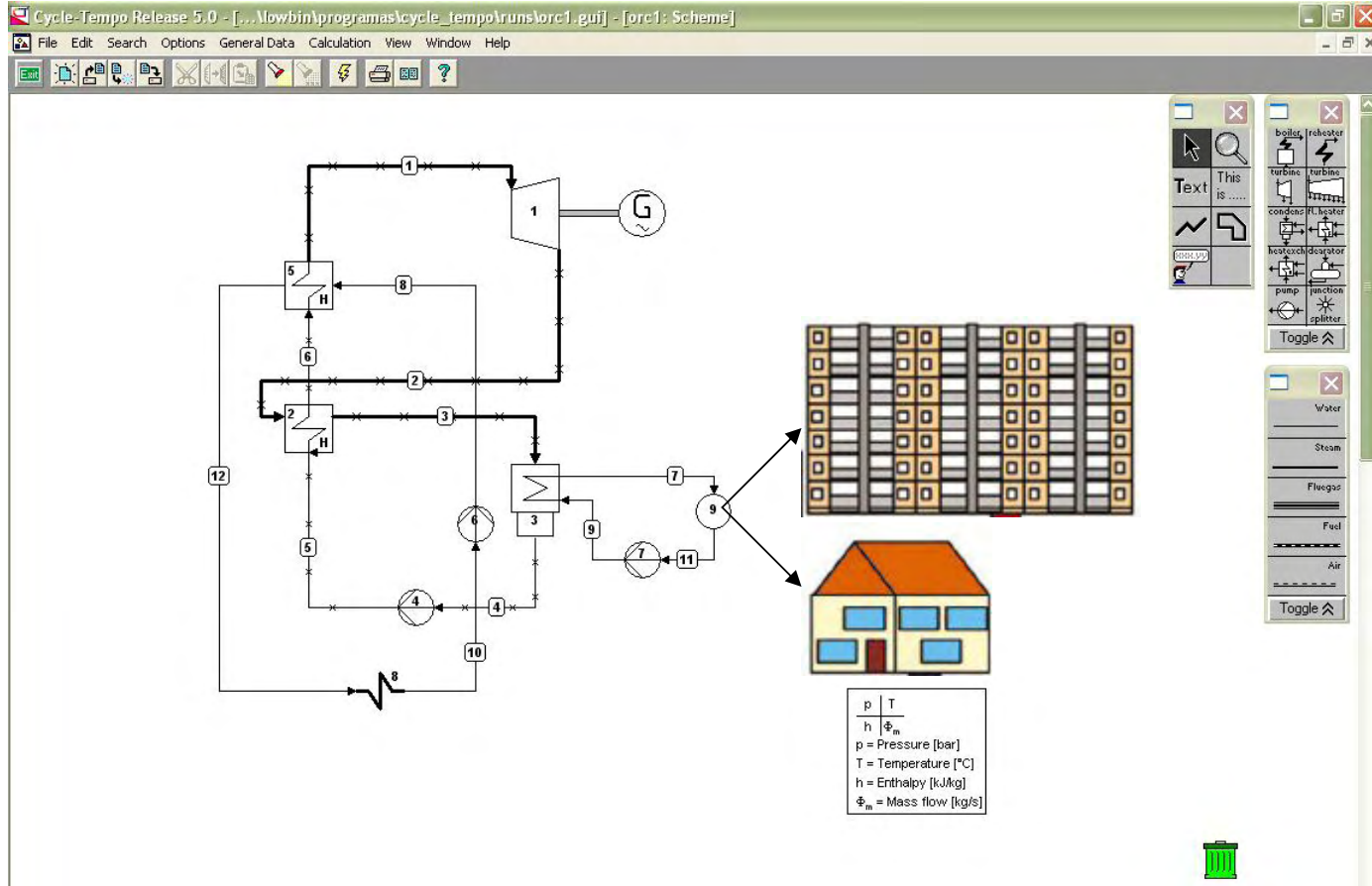


CYCLE-TEMPO COMPUTER PROGRAM

• Applications:

- steam turbine cycles
- gas turbine cycles
- combined cycle plants
- combustion and gasification systems
- heat transfer systems
- fuel cell systems (with low temperature as well as high temperature fuel cells)
- • organic Rankine cycles (ORC)
- refrigeration systems (compression and absorption cycles)
- heat pumps

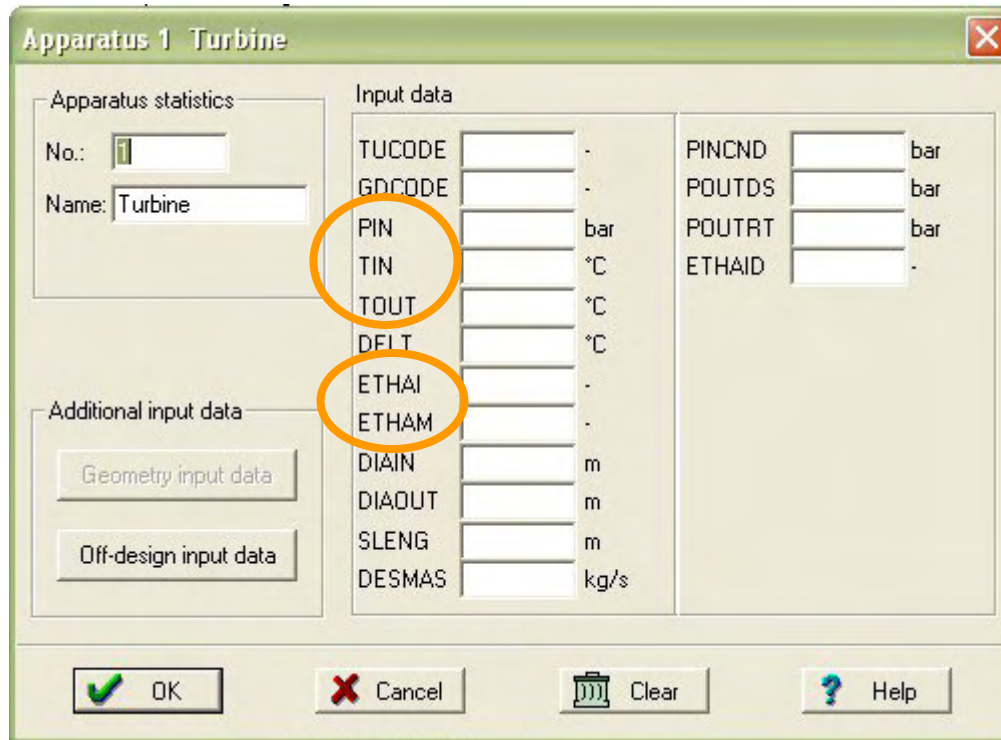
CYCLE-TEMPO COMPUTER PROGRAM – Drawing the cycle



- For prototype to generate electricity from low temperature geothermal
- For prototype to cogeneration of heat and power (120-150°C)

CYCLE-TEMPO COMPUTER PROGRAM – Input (turbine)

- Data input is made by filling property dialog boxes



Parameter	Unit
TUCODE	-
GDCODE	-
PIN	bar
TIN	°C
TOUT	°C
DEL T	°C
ETHAI	-
ETHAM	-
DIAIN	m
DIAOUT	m
SLENG	m
DESMAS	kg/s
PINCND	bar
POUTDS	bar
POUTRT	bar
ETHAID	-



CYCLE-TEMPO COMPUTER PROGRAM – Input (heat exchanger)

Apparatus 2 Heat Exchgr.

Apparatus statistics No.: <input type="text" value="2"/> Name: <input type="text" value="Heat Exchgr."/> Type: <input type="text" value="General"/>		Input data EEQCOD <input type="text"/> - PIN1 <input type="text"/> bar POUT1 <input type="text"/> bar DELP1 <input type="text"/> bar TIN1 <input type="text"/> °C TOUT1 <input type="text"/> °C DELT1 <input type="text"/> °C DELE <input type="text"/> kW RPSM <input type="text"/> - PIN2 <input type="text"/> bar POUT2 <input type="text"/> bar DELP2 <input type="text"/> bar		TIN2 <input type="text"/> °C TOUT2 <input type="text"/> °C DELT2 <input type="text"/> °C DELTL <input type="text"/> °C DELTH <input type="text"/> °C	
Additional input data <input type="button" value="Furnace input data"/> <input type="button" value="Off-design input data"/>		<input type="button" value="OK"/> <input type="button" value="Cancel"/> <input type="button" value="Clear"/> <input type="button" value="Help"/>			



CYCLE-TEMPO COMPUTER PROGRAM – Input (condenser)

Apparatus 3 Condenser

Apparatus statistics

No.:

Name:

Additional input data

Input data

EEQCOD	<input type="text"/>	-	TIN2	<input type="text"/>	°C
PIN1	<input type="text"/>	bar	TOUT2	<input type="text"/>	°C
POUT1	<input type="text"/>	bar	DEL2	<input type="text"/>	°C
DELP1	<input type="text"/>	bar	DELTL	<input type="text"/>	°C
TIN1	<input type="text"/>	°C	DELTH	<input type="text"/>	°C
TOUT1	<input type="text"/>	°C	SATCOD	<input type="text"/>	-
DEL1	<input type="text"/>	°C	DTSUBC	<input type="text"/>	°C
DELE	<input type="text"/>	kW			
RPSM	<input type="text"/>	-			
PIN2	<input type="text"/>	bar			
POUT2	<input type="text"/>	bar			
DELP2	<input type="text"/>	bar			





CYCLE-TEMPO COMPUTER PROGRAM – Input (pump)

The screenshot shows a software window titled "Apparatus 4 Pump" with a close button in the top right corner. The window is divided into several sections:

- Apparatus statistics:** Contains a "No.:" field with the value "4" and a "Name:" field with the value "Pump".
- Additional input data:** Contains two buttons: "Geometry input data" and "Off-design input data".
- Input data:** A table with the following parameters and units:

PIN		bar
POUT		bar
DELT		bar
TIN		°C
TOUT		°C
DELT		°C
ETHAI		-
ETHAM		-
ETHAE		-

At the bottom of the window, there are four buttons: "OK" (with a green checkmark), "Cancel" (with a red X), "Clear" (with a trash can icon), and "Help" (with a question mark icon). The fields for "POUT" and "DELT" in the "Input data" section are circled in orange.



CYCLE-TEMPO COMPUTER PROGRAM – Input (shaft and generator)

Shaft dialog

Surplus Power: MW

Generator no. 1

Apparatus statistics

No.:

Name:

Input data

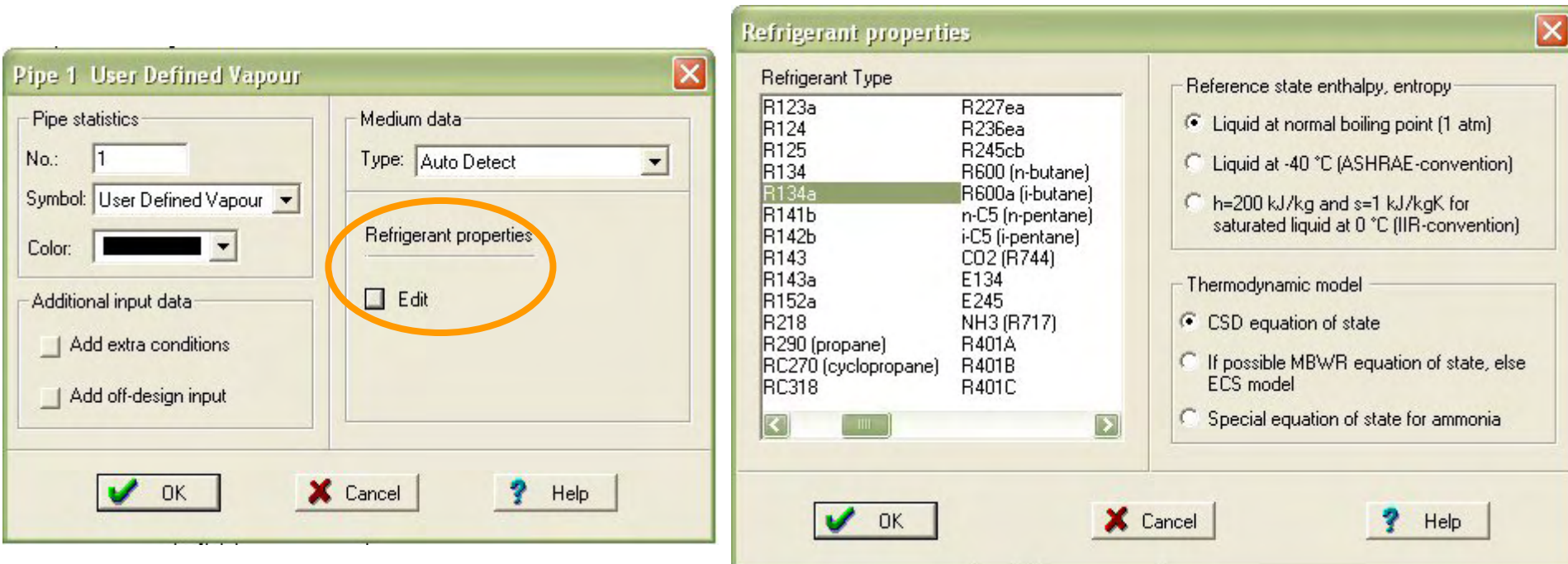
ETAGEN	-
CBSPHI	-
GENMVA	MVA
KTURB	-
KGEN	-
CPRATI	-

Additional input data



CYCLE-TEMPO COMPUTER PROGRAM – Input (pipe and fluid)

REFPROP library



The image shows two overlapping dialog boxes from the CYCLE-TEMPO software. The left dialog box is titled 'Pipe 1 User Defined Vapour' and contains fields for 'Pipe statistics' (No.: 1, Symbol: User Defined Vapour, Color: black), 'Additional input data' (Add extra conditions, Add off-design input), and 'Medium data' (Type: Auto Detect). A 'Refrigerant properties' section is highlighted with an orange circle, containing an 'Edit' checkbox. The right dialog box is titled 'Refrigerant properties' and shows a list of refrigerant types with 'R134a' selected. It also includes options for 'Reference state enthalpy, entropy' (Liquid at normal boiling point (1 atm) selected) and 'Thermodynamic model' (CSD equation of state selected).

Pipe 1 User Defined Vapour

Pipe statistics

No.: 1

Symbol: User Defined Vapour

Color: [Black]

Additional input data

Add extra conditions

Add off-design input

Medium data

Type: Auto Detect

Refrigerant properties

Edit

OK Cancel Help

Refrigerant properties

Refrigerant Type

R123a	R227ea
R124	R236ea
R125	R245cb
R134	R600 (n-butane)
R134a	R600a (i-butane)
R141b	n-C5 (n-pentane)
R142b	i-C5 (i-pentane)
R143	CO2 (R744)
R143a	E134
R152a	E245
R218	NH3 (R717)
R290 (propane)	R401A
RC270 (cyclopropane)	R401B
RC318	R401C

Reference state enthalpy, entropy

Liquid at normal boiling point (1 atm)

Liquid at -40 °C (ASHRAE-convention)

h=200 kJ/kg and s=1 kJ/kgK for saturated liquid at 0 °C (IIR-convention)

Thermodynamic model

CSD equation of state

If possible MBWR equation of state, else ECS model

Special equation of state for ammonia

OK Cancel Help



CYCLE-TEMPO COMPUTER PROGRAM – Input (REFPROP)

- Developed and maintained by the National Institute of Standard and Technologies
- Included fluids and mixtures:
 - The HFCs R23, R32, R41, R125, **R134a**, R143a, R152a, **R227ea**, R236ea, **R236fa**, R245ca, and **R245fa**
 - The HCFCs R22, R123, R124, R141b, and R142b
 - The traditional CFCs R11, R12, R13, R113, R114, and R115
 - The fluorocarbons R14, R116, R218, and **RC318**
 - Ammonia, carbon dioxide, isobutane, and **propylene**
 - The main air constituents nitrogen, oxygen, and argon
 - Methane, **ethane**, **propane**, butane, and **isobutane**
 - Water (as a pure fluid, or mixed with ammonia)
 - 35 predefined mixtures (such as R407C, R410A, and Air)
 - the user may define and store others



CYCLE-TEMPO COMPUTER PROGRAM – Input (REFPROP)

- Available properties:

Temperature, Pressure, Density, Energy, Enthalpy, Entropy, C_v , C_p , Sound Speed, Compressibility Factor, Joule Thompson Coefficient, Quality, 2nd Virial Coefficient, 3rd Virial Coefficient, Helmholtz Energy, Gibbs Energy, Heat of Vaporization, Fugacity, Fugacity Coefficient, K value, Molar Mass, Thermal Conductivity, Viscosity, Kinematic Viscosity, Thermal Diffusivity, Prandtl Number, Surface Tension, Isothermal Compressibility, Volume Expansivity, Isentropic Coefficient, Adiabatic Compressibility, Specific Heat Input, Exergy, dp/dr , d^2p/dr^2 , dp/dT , dr/dT , dr/dp





CYCLE-TEMPO COMPUTER PROGRAM – Input (cold source)

Apparatus 9 Sink/Source

Apparatus statistics

No.:

Name: Sink/Source

Additional input data

Input data

PIN	<input type="text"/>	bar	XOUT	<input type="text"/>	-
POUT	<input type="text"/>	bar	PIPE	<input type="text"/>	-
DELP	<input type="text"/>	bar	ESTMAS	<input type="text"/>	kg/s
TIN	<input type="text"/>	°C	LHV	<input type="text"/>	kJ/kg
TOUT	<input type="text"/>	°C	SUBTYP	<input type="text"/>	-
DELT	<input type="text"/>	°C	DTSUBC	<input type="text"/>	°C
DELE	<input type="text"/>	kW	DTSUPH	<input type="text"/>	°C
DELM	<input type="text"/>	kg/s	WFOT	<input type="text"/>	-
HIN	<input type="text"/>	kJ/kg	ESTTIN	<input type="text"/>	°C
HOUT	<input type="text"/>	kJ/kg	ESTTOU	<input type="text"/>	°C
DELH	<input type="text"/>	kJ/kg	DELV	<input type="text"/>	m3/s
XIN	<input type="text"/>	-	DELVN	<input type="text"/>	nm3/s





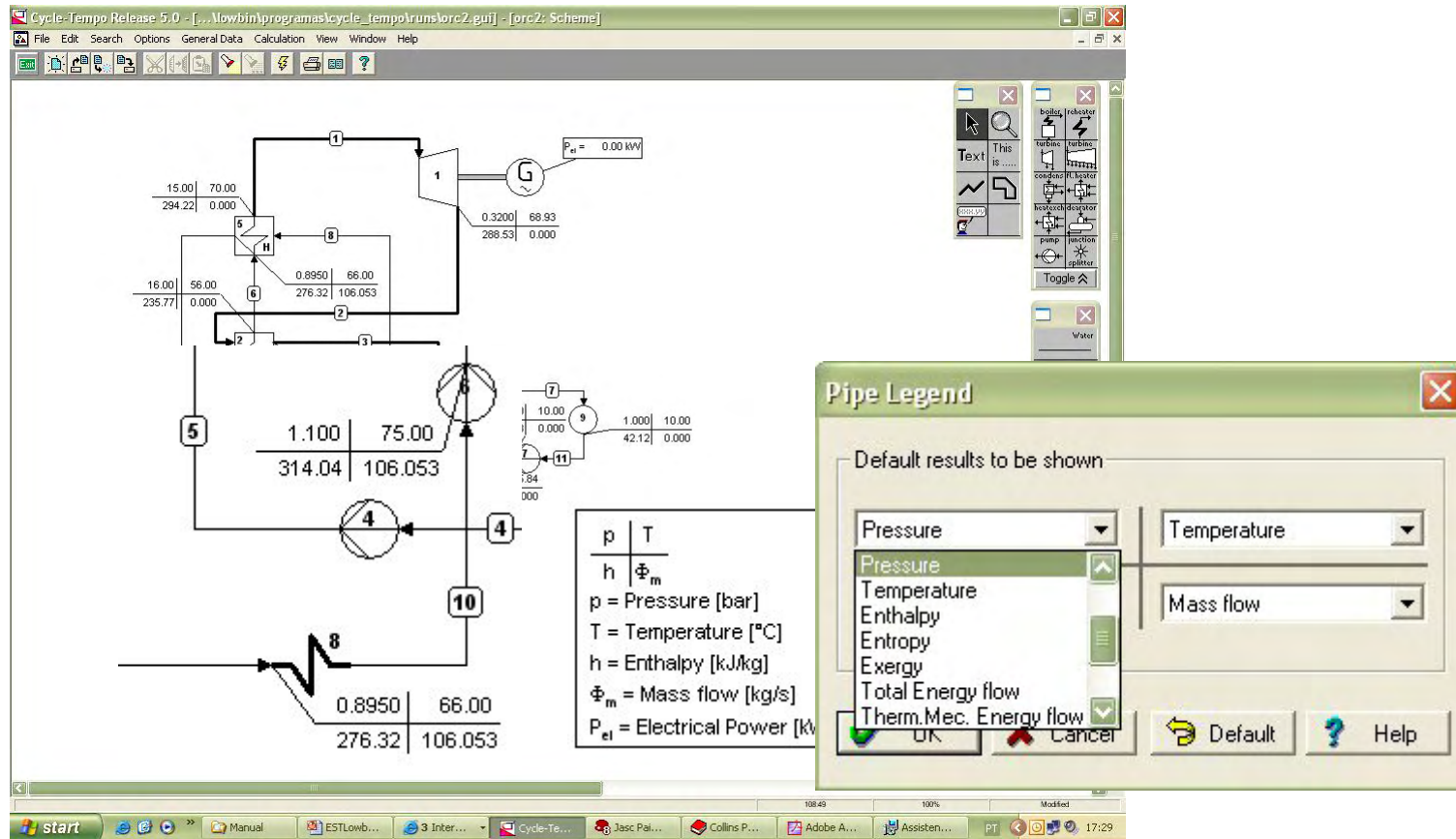
CYCLE-TEMPO COMPUTER PROGRAM – Input (hot source)

Apparatus 8 Reheater

Apparatus statistics		Input data	
No.:	<input type="text"/>	PIN	<input type="text"/> bar
Name:	<input type="text" value="Reheater"/>	POUT	<input type="text"/> bar
Additional input data		DELP	<input type="text"/> bar
<input type="button" value="Geometry input data"/>		TIN	<input type="text"/> °C
<input type="button" value="Off-design input data"/>		TOUT	<input type="text"/> °C
		DELT	<input type="text"/> °C
		DELM	<input type="text"/> kg/s
		DELE	<input type="text"/> kW
		ESTMAS	<input type="text"/> -
		ETHAB	<input type="text"/> -
		LHV	<input type="text"/> kJ/kg
		EXFUEL	<input type="text"/> kJ/kg

CYCLE-TEMPO COMPUTER PROGRAM – Results in the Diagram

- Results are available as well ordered charts, plots and tables



CYCLE-TEMPO COMPUTER PROGRAM – Results in Tables

Name of table | **Condition for generation**

System Energy Compo

Setup table with calculation results

Table name: Table 12

absorbed > 0

compositions

ex1: System efficiencies

	No.	Apparatus	Type	Energy [kW]	Totals [kW]	Exergy [kW]	Totals [kW]
Absorbed power	1	Boiler	1	309406.19	309406.19	322901.16	322901.16
Delivered gross power	1	Generator	G	100000.00	100000.00	100000.00	100000.00
Aux. power consumption	4	Pump	8	69.36		69.36	
	6	Pump	8	1315.14		1315.14	
	8	Pump	8	3874.27		3874.27	
					5258.78		5258.78
Delivered net power					94741.23		94741.23
Efficiencies	gross			32.320 %		30.969 %	
	net			30.620 %		29.341 %	

ex1: Energy balance

No.	Name	Type	Energy loss (enthalpy) [kW]	Energy loss (HHV) [kW]	Energy loss (LHV) [kW]
1	Boiler	1	-293935.88	-293935.88	-293935.88
2	Turbine	3	103092.78	103092.78	103092.78
3	Condensor	4	0.00	0.00	0.00
5	Deaerator	7	0.00	0.00	0.00
4	Pump	8	-61.86	-61.86	-61.86
6	Pump	8	-1249.75	-1249.75	-1249.75
8	Pump	8	-3692.14	-3692.14	-3692.14
7	Sink/Source	10	195846.84	195846.84	195846.84
1	Pipe		0.00	0.00	0.00
4	Pipe		0.00	0.00	0.00
8	Pipe		0.00	0.00	0.00
	Total:		0.00	0.00	0.00

Motors

Heat ex

2 7

3 8

4 9

Add->

Delete

Help

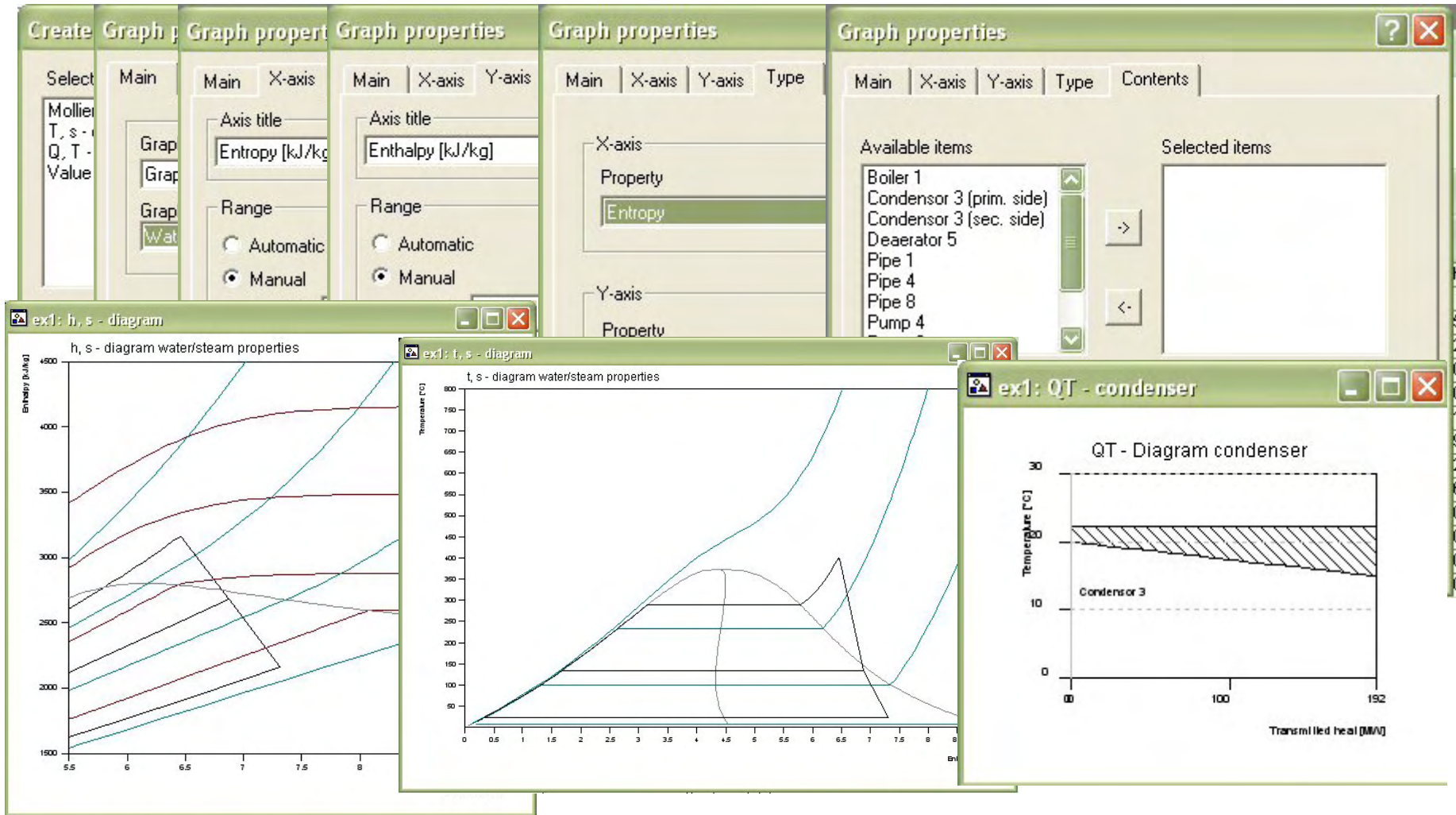
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(type 22) > 0

CYCLE-TEMPO COMPUTER PROGRAM – Results in Diagram



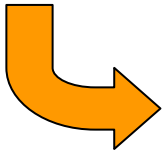
NEXT – WP#2

Evaluation of working fluids:

Acquire REFPROP8 to study different working fluids



calculate CYCLE-TEMPO results for LOWBIN prototypes conditions with REFPROP8 working fluids



choose the best working fluids for each LOWBIN prototypes

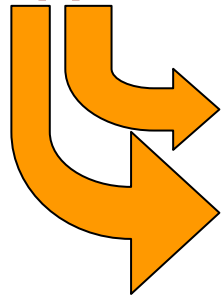
Technology assessment of heat exchangers

- Research of most used heat exchangers types for this kind of applications
- Research and acquisition of a program to design the heat exchanger, aiming the lowest temperature operation threshold

NEXT – WP#3

Pre-prototype development and laboratory measurements

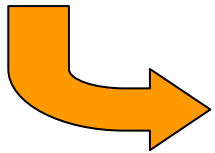
Application of the information obtain in the previous WP



specifying working fluids and heat exchangers

optimizing the heat exchanger

Utilization of Cycle-Tempo



study modifications in the cycle (components; temperatures variations...), to optimize the pre-prototype

Environmental impacts study

NEXT – WP#5

Monitoring and analysing geothermal energy parameters,

Continuing the calculations with the model



To help to define the most important measurement points

Evaluation and analysis of monitored parameters

Evaluation of Cycle-Tempo performance

Technology validation report

WP#6

Presentations in conferences and papers in scientific journals

Submission of scientific articles with the achieved results

Partners suggestions...

For example for apparatus input data for LOWBIN prototypes, such as temperatures of cold and hot sources...

thank you for your attention

σας ευχαριστώ

grazie

dankeschön

dankchen

mulțumesc

obrigada

merci

takk fyrir